

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE  
APPLICATION FOR U.S. LETTERS PATENT

Title:

PIXEL SIGNAL BINNING AND INTERPOLATION IN COLUMN CIRCUITS OF  
A SENSOR CIRCUIT

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## **PIXEL SIGNAL BINNING AND INTERPOLATION IN COLUMN CIRCUITS OF A SENSOR CIRCUIT**

### **FIELD OF THE INVENTION**

[0001] The present invention relates generally to image sensors, and, in particular, to charge-domain analog readout circuits for such sensors.

### **BACKGROUND OF THE INVENTION**

[0002] Image sensors find applications in a wide variety of fields, including machine vision, robotics, guidance and navigation, automotive applications, and consumer products. In many smart image sensors, it is desirable to integrate on-chip circuitry to control the image sensor and to perform signal and image processing on the output image. Unfortunately, charge-coupled devices (CCD), which have been one of the dominant technologies used for image sensors, do not easily lend themselves to large scale signal processing and are not easily integrated with CMOS circuits. Moreover, a CCD is read out by sequentially transferring the signal charge through the semiconductor, and the readout rate is limited by the need for nearly perfect charge transfer.

[0003] Active pixel sensors (APS), which have one or more active transistors within the pixel unit cell, can be made compatible with CMOS technologies and promise higher readout rates compared to passive pixel sensors. Active pixel

sensors are often arranged as arrays of elements, which can be read out, for example, a column at a time. Each column can be read out at one time, driven and buffered for sensing by a readout circuit.

[0004] FIG. 1 shows an exemplary CMOS active pixel sensor integrated circuit chip that includes an array of active pixel sensors 30 and a controller 32 that provides timing and control signals to enable the reading out of signals stored in the pixels. Exemplary arrays have dimensions of N by M pixels and, in general, the size of the array 30 will depend on the particular implementation. The imager is read out a row at a time using a column parallel readout architecture. The controller 32 selects a particular row of pixels in the array 30 by controlling the operation of vertical addressing circuit 34 and row drivers 40. Charge signals stored in the selected row of pixels are provided to a readout circuit 42. The pixels of the columns can be read out sequentially using a horizontal addressing circuit 44. Typically, each pixel provides a reset output signal  $V_{out1}$  and a signal representing accumulated charge during an integration period  $V_{out2}$  which are provided at the output of the readout circuit 42.

[0005] As shown in FIG. 2, the array 30 includes multiple columns 49 of CMOS active pixel sensors 50. Each column 49 includes multiple rows of sensors 50. Signals from the active pixel sensors 50 in a particular column can be read out

to a readout circuit 52 associated with that column. Signals stored in the readout circuits 52 can be sent to an output stage 54, which is common to the entire array of pixels 30. The analog output signals can then be sent, for example, to a differential analog-to-digital converter (ADC).

[0006] Excessive noise and slow frame rates are introduced during the read process of the differential charge mode readout from the columns of the CMOS image sensor. To compensate for this, current readout circuitry uses subsampling (under a sub-resolution mode) to increase the frame rate. In most imaging applications, a pixel is captured with each pulse of the pixel clock (except during blanking). Subsampling increases frame rates by capturing pixels at a rate slower than the base pixel clock frequency. For example, one pixel can be captured for every two pulses of the pixel clock to provide an effective sampling rate that is  $\frac{1}{2}$  the base pixel clock frequency. The use of subsampling allows a higher frequency pixel clock rate to clock lower-frequency sampling.

[0007] During subsampling, however, pixels are read out sequentially, but not contiguously. In other words, some pixels are skipped to obtain a lower resolution in exchange for a potentially higher frame rate. What is needed is an image sensor where the readout circuitry has improved sub-resolution characteristics with reduced aliasing.

## **BRIEF SUMMARY OF THE INVENTION**

[0008] In general, embodiments of the invention provide an imaging circuit, system, and related methods for incorporating signal binning into the readout circuitry. Binning is defined as accumulating or interpolating the charge of multiple pixels and reading them out in a single operation. By incorporating binning into the readout circuitry, various sub-resolution processes can be implemented to minimize aliasing effects. Additionally, by using analog processing for the binning, signal bandwidth may be reduced. This in turn reduces the overall power requirements of the sensor. An additional benefit to using analog binning is that the signal-to-noise ratio (SNR) advantages achieved from binning are more pronounced in the analog domain than they are in the digital domain.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

[0009] These and other features and advantages of the invention will be more clearly seen from the following detailed description of the invention which is provided in connection with the accompanying drawings in which:

[0010] FIG. 1 is a block diagram of an exemplary prior art CMOS active pixel sensor chip;

[0011] FIG. 2 is a block diagram of a conventional array of active pixel sensors and a readout circuit;

[0012] FIG. 3 is an exemplary charge mode readout circuit;

[0013] FIG. 4 shows vertical binning by implementing a split-capacitor configuration in accordance with an exemplary embodiment of the invention;

[0014] FIG. 5 illustrates a horizontal averaging scheme among column lines in accordance with another exemplary embodiment of the invention;

[0015] FIG. 6 illustrates a  $\frac{1}{2}$  capacitance line averaging circuit according to another exemplary embodiment of the invention;

[0016] FIG. 7 shows an exemplary color averaging operation for the circuit of FIG. 6;

[0017] FIG. 8 illustrates an exemplary color averaging process for a first square of a pixel matrix in accordance with an exemplary embodiment of the invention;

[0018] FIG. 9 illustrates an exemplary color averaging process for a second square of a pixel matrix in accordance with an exemplary embodiment of the invention;

[0019] FIG. 10 illustrates an exemplary color averaging process for third and fourth squares of a pixel matrix in accordance with an exemplary embodiment of the invention;

[0020] FIG. 11 shows a binned pixel matrix after the averaging process of FIGs. 8-10;

[0021] FIG. 12 is an exemplary configuration according to the invention that realizes a VGA Bayer pattern, where pixels are averaged from three rows and three columns;

[0022] FIG. 13 illustrates a 2/3 resolution binning scheme according to the present invention, where two rows from three columns of a pixel matrix are averaged;

[0023] FIG. 14 illustrates a binning scheme according to the present invention, where every third column is skipped in order to average out two columns and two rows;

[0024] FIG. 15A illustrates an exemplary horizontal binning scheme that realizes a 1024x768 RGB resolution in accordance with another embodiment of the invention;

[0025] FIG. 15B illustrates an exemplary horizontal binning scheme that realizes a 1280x1024 RGB resolution in accordance with yet another embodiment of the invention;

[0026] FIG. 15C illustrates an exemplary horizontal binning scheme that realizes a "1/3 skip" VGA Bayer resolution in accordance with yet another embodiment of the invention;

[0027] FIG. 16 illustrates a Mg-Cy-Ye-G filter array from which color separation values are calculated in accordance with yet another embodiment of the invention;

[0028] FIG. 17 illustrates a block diagram of an imaging apparatus in accordance with yet another embodiment of the invention; and

[0029] FIG. 18 illustrates a processing system that uses a binning circuit constructed in accordance with any of the embodiments of the invention.

## **DETAILED DESCRIPTION OF THE INVENTION**

[0030] FIG 3. illustrates a differential charge-domain readout circuit 150 for an image sensor, wherein a column readout circuit 100 receives a signal from a pixel along a column line 101. Examples of such circuitry may be found in commonly-



assigned U.S. patent no. 6,222,175, which is incorporated by reference in its entirety herein. The readout circuit 100 includes a load transistor 102 that receives a signal (VLN) at its gate. As is known in the art, the VLN signal activates the load transistor 102 such that it provides a load on the column line 101. The column line 101 is further coupled to two sample-and-hold circuits for storing a pixel signal level when a first sample-and-hold signal (SHS) is applied and a reset level when a second sample-and-hold signal (SHR) is applied to the readout circuit 150. Sampling both the reset and pixel signal levels allows correlated double sampling (CDS) to be performed, which can reduce reset noise associated with the connected pixel as well as noise associated with the source-follower circuitry in the pixel sensor.

[0031] The first sample-and-hold circuit includes a switch 103, which may be implemented as a transistor, and a capacitor 106. The first sample-and-hold signal SHS is applied to the switch 103 to control whether the switch 103 is in a conductive or non-conductive state. The second sample-and-hold circuit also includes a switch 104, which also may be implemented as a transistor, and a capacitor 107. The second sample-and-hold signal SHR is applied to the switch 104 to control the state of the switch 104. Capacitors 106, 107 can be held at a reference voltage (VCL) by closing switches 109, and 108, respectively. The signal

clampS controls the state of switch 109, and the signal clampR controls the state of switch 108.

[0032] In addition to the sample-and-hold circuits, the column readout circuit 100 includes a crowbar switch 105, which also may be implemented as a transistor. The state of the crowbar transistor 105 is controlled by an external crowbar control signal (CB). Use of the crowbar switch 105 can help reduce fixed pattern noise (FPN) caused by column-to-column variations due to the column parallel readout structure (described above).

[0033] Signals stored by the capacitors 106, 107 can be transmitted to the output stage 120 through respective column select switches 110, 111, which may be implemented as transistors. The column selection signal (ColSel) applied to the, switches 110, 111 controls whether those switches 110, 111 are conductive or non-conductive. When the column selection switch 110 (or 111) is turned on, the sampling capacitor 106 (or 107) is coupled directly to a bus 117 (or 118) connected to the output stage 120. It should be appreciated that both switches 110, 111 may be closed at the same time if desired. It should also be understood that any other suitable storage device may be substituted for the capacitors 106, 107.

[0034] As mentioned previously, the output stage 120 of the charge-domain readout circuit 150 is common to the entire array 30 of pixels. Thus, although

only a single circuit 150 is illustrated in FIG. 3, multiple column readout circuits are coupled to the output stage 120. The output stage 120 includes a switched integrator, which further includes a differential operational amplifier 112, two feedback capacitors 113, 114, respectively coupled between the output  $V_{out1}$ ,  $V_{out2}$  and the negative and positive terminals of the operational amplifier 112. Reset switches 115, 116 are respectively coupled between the output  $V_{out1}$ ,  $V_{out2}$  and the negative and positive terminals of the operational amplifier 112. Each integrator output stage 120 can be selectively reset by turning on the associated reset switch 115, 116 using a signal  $Rst\_amp$ . The operational amplifier 112 provides two output signals  $V_{out1}$ ,  $V_{out2}$  that are then transmitted to the analog-to-digital converter (not shown in FIG. 3).

[0035] FIG. 4 illustrates an embodiment of the invention, wherein vertical binning is implemented in the readout circuit 100 of FIG. 3. The capacitors 106, 107 of FIG. 3 are “split out” in the illustrated exemplary embodiment of FIG. 4. The capacitive value of capacitors 106, 107 are replaced by multiple smaller capacitive elements 209-216, which each make up a fraction (e.g.,  $\frac{1}{4}$ ) of the original capacitance. Each capacitor 209-216 is coupled to a respective switch 201-208, where each switch 201-208 is controllable to obtain different resolutions for an array 30 (FIG. 2) under a predetermined sampling sequence. For example, if all the switches 201-208 are closed during operation, the capacitors 209-216 would

essentially behave as one capacitor (i.e., full resolution), and the effective capacitance would be the same as that shown in FIG. 3. It should be understood that, while the embodiment in FIG. 4 shows a four-capacitor configuration (i.e., each capacitor being split into 4 capacitive elements), any number of capacitor splits (2, 3, 4, 6, etc.) may be used. As another example, if only half of the switches are closed, the readout circuit would be in a 1/2 resolution condition.

[0036] As an example, the embodiment of FIG. 4 may be used with monochrome sensor schemes where the sensor may be configured to support full resolution,  $\frac{1}{2}$  resolution and  $\frac{1}{4}$  resolution in the vertical direction. For the sake of simplicity, it is assumed in the example that the horizontal resolution is defined outside the chip. Under  $\frac{1}{2}$  resolution, the signal received from a first row of the array is sampled and stored on two of the capacitors (e.g., capacitors 209-210 and 213-214) by enabling the respective switches (e.g., switches 201-202 and 205-206) associated with those capacitors. Signals received from a second row are sampled and stored on the two other capacitors (e.g., capacitors 211-212 and 215-216) by enabling their respective switches (e.g., switches 203-204 and 207-208). After sampling the data (during a crowbar operation), the left plates of the capacitors 209-216 are shorted, wherein an averaged signal of the first and second rows is outputted. It should be noted that the gain of the circuit of FIG. 4 remains stable during this operation, which adds flexibility in using the circuit.

[0037] Under a  $\frac{1}{4}$  resolution operation, signals received from the first four rows of a column are separately sampled to a respective capacitor 209-212, 213-216. After the four rows are stored, the left plates of the capacitors 209-216 are shorted to output an averaged signal among the four rows for the particular column.

[0038] Bayer patterns are typically used to acquire color images when color sensing is used. Bayer color filter arrays are known in the art and are used to digitally acquire color images. The Bayer pattern of color filters are such that half the total number of pixels are green, while a quarter of the remaining pixels are red, and a quarter of the remaining pixels are blue.

[0039] Under a  $\frac{1}{2}$  resolution operation for a 4-row pixel, a color signal from a first row is read out and sampled on the first two capacitors 209-210, 213-214 of each sample line (i.e., pixel signals on capacitors 209-210, reset signals on capacitors 213-214). Next, the signal on the third row is sampled to the other two capacitors 211-212, 215-216 of the sample lines. The four capacitors 209-212, 213-216 from each sample line are then shorted together; the averaged sum for rows 1 and 3 are read out (via switches 110, 111). The same process is repeated with rows 2 and 4, where the row signals are averaged and read out as described above.

[0040] The  $\frac{1}{4}$  resolution readout process for color signals is similar to the  $\frac{1}{2}$  resolution described above, where rows 1, 3, 5, and 7 are first stored on a respective capacitor 209-212, 213-216, averaged and read out; subsequently, rows 2, 4, 6, and 8 are stored on a respective capacitor 209-212, 213-216, averaged and read out.

[0041] Turning to FIG. 5, another embodiment of the invention is illustrated, where each binning circuit 500 has a sample and hold pixel signal and sample and hold reset signal node coupled to a neighboring circuit 501 via respective switches 502, 503. Binning circuit 501 also connects to a neighboring binning circuit (not shown) through switches 504, 505. Additional binning circuits can be added as required, and the outputs (BIN1 and BIN2) carry a "horizontally" averaged signal (i.e., average signal between the column circuits).

[0042] When using the circuit of FIG. 5 in a monochrome sensor, averaged signals from the binning circuits 500, 501 are added together between the odd and even neighboring columns (discussed in greater detail below in connection with FIGs. 15A-C). For color sensors, the columns are read out in accordance with the Bayer pattern (discussed above). The range of averaging and the number of shorted columns can be adjusted depending on the resolution required. It should

also be understood that the circuits and methods described herein are equally applicable to other types of imaging devices (e.g., charge-couple devices (CCDs)).

[0043] FIG. 6 illustrates another embodiment of the invention, wherein the readout circuit 650 is similar to that discussed in FIG. 4, except that each capacitor 604-605, 606-607 of a sample line makes up one-half ( $C/2$ ) of each sample line capacitance (as opposed to the one-quarter shown in FIG. 4). Each capacitor 604-607 is coupled to a respective switch 600-603. Each of the switches 600-603 are controllable to obtain different (i.e., less-than-full and full) resolutions for the circuit 650 when opened and closed.

[0044] The readout circuit 650 of FIG. 6 may be operated to sum together charges of the same pixel color in each column. The result from this kind of operation emulates that of a high resolution "skip mode" used in CCD devices, such as that used in the Sony ICX252AQ 3 Megapixel CCD. An exemplary operation of the FIG. 6 circuit 650 is shown in FIG. 7, where the row selection algorithm in the readout circuit is configured to read out red colors (R) from rows 1 and 3 (700) and store them on capacitors 604-605. The reset signals from rows 1 and 3 are also read out (not shown) and stored on capacitors 606, 607. The left plates of the capacitors 604-607 are then shorted to output an averaged signal of the red colors of first and the third row.

[0045] The process of FIG. 7 continues with the green color (Gr) of rows 1 and 3, where the green colors (Gr) are read out (700) and stored on capacitors 604-605. The reset signals of the Gr pixels from rows 1 and 3 are also read out (not shown) and stored on capacitors 606, 607. The left plates of the capacitors 604-607 are then shorted to output an averaged signal of the Gr colors of first and the third row. Next the green (Gb) and blue (B) signals from rows 8 and 10 are read out (701) in a similar fashion, then rows 13 and 15 (703) are read out as shown in FIG. 6, and so on.

[0046] For emulation of a 4 megapixel CCD (e.g., Sony ICX406AQ 4 megapixel (Meg) CCD) in high frame readout mode, rows 1 and 5, 10 and 14, 17 and 21, etc. are summed in a manner identical to that described above. To realize this exemplary binning scheme, the circuit discussed in FIGs. 6-7 may be used, where the row selection algorithm is adjusted to accommodate the readout order.

[0047] FIGs. 8-10 disclose another sub-resolution scheme for a 3 Meg sensor. The maximum (full) resolution for a 3 Meg sensor is approximately 2048x1536. Exemplary sub-resolutions for the 3 Meg sensor are 1280x1024 (2/3 resolution), 1024x768 (1/2 resolution), and 640x480 (1/4 resolution). In order to accurately read out the sub-resolution pixel signals, it is necessary to average out the pixel signals.



[0048] FIG. 8 shows an exemplary 6x6 pixel matrix 810, where the colors of the matrix 810 are arranged in a Bayer pattern, and where rows that are being read out are shown as illuminated (i.e., not shaded). The Bayer pattern consists of first (Gr) and second (Gb) green pixels, a red (R) pixel, and a blue (B) pixel. Gr and R color pixels alternate in odd rows 1,3, 5, etc. B and Gb color pixels alternate in even rows 2, 4, 6, etc. Under a 2/3 readout scheme in the exemplary embodiment (i.e., 2/3 of the full resolution), rows 1 and 3 are read out from a first 3x3 square 820 of matrix 810, and stored in a readout circuit, such as one described above for FIG. 4. During the first pass (800), the switches in the readout circuit are arranged to first average the first green pixels from rows 1 and 3 as follows:  $Gr(1,1) + Gr(1,3) + Gr(3,1) + Gr(3,3)$ , where the format  $Gr(1,3)$  designates the green pixel in row 1, column 3,  $Gr(3,1)$  designates the green pixel in row 3, column 1, and so on. After the first green pixels from rows 1 and 3 are averaged out, the averaging process moves to the red pixels (801), wherein the summation of  $R(1,2) + R(3,2)$  is executed.

[0049] After the first pixel square 820 is read out, the process continues to the second pixel square 821, where the Gr pixels are read out (802) and averaged according to  $Gr(1,5) + Gr(3,5)$ , and red pixels are read out (803) and averaged according to  $R(1,4) + R(1,6) + R(3,4) + R(3,6)$ . As can be appreciated by those skilled in the art, the fifth column (802) is read out prior to the fourth and sixth

columns (803) in order to preserve the Bayer pattern. After squares 820 and 821 are read out and averaged, the process moves on to the second pass, illustrated in FIG. 9.

[0050] In FIG. 9, the second row is processed with the blue pixels in the first pixel square 820 being read out and averaged (900) according to  $B(2,1) + B(2,3)$ . Next, the second green pixel (Gb) is read out (901), but is not averaged, since it is the only pixel color in the row for the square 820. The process continues to the second square 821, where the blue pixel is read out (902), but not averaged, and the second green pixels (Gb) are read out and averaged (902) according to  $G_b(2,4) + G_b(2,6)$ . For a more simplified algorithm, the second green pixel (Gb) (901) may be skipped, or alternately read out and added to the first green pixels (Gr) from the first pass with a relative weight of 1/5th.

[0051] Turning to FIG. 10, the averaging process proceeds to the third 822 and fourth 823 squares of matrix 810, where the fifth row is read out under a first pass (810A), followed by the 4th and 6th row in a second pass (810B). In the first pass, starting with the third square 822, the first green pixels (Gr) for the fifth row are read out, and are averaged (1000) according to  $Gr(5,1) + Gr(5,3)$ , followed by the reading out of the red pixel (1001)  $R(5,2)$  in square 822. Turning to the fourth square 823, the one first green pixel (Gr) in the fifth row  $Gr(5,5)$  is read out (1002),

followed by the reading out of the red pixels, which are read out and averaged (1003) according to  $R(5,4) + R(5,6)$ .

[0052] Continuing, the 4th and 6th rows are read out in the second pass. Starting in square 822, the blue pixels are read out and averaged (1004) according to  $B(4,1) + B(4,3) + B(6,1) + B(6,3)$ . Next, the second green pixels (Gb) are read out and averaged (1005) according to  $Gb(4,2) + Gb(6,2)$ . Moving to square 823, the blue pixels are read out and averaged (1006) according to  $B(4,5) + B(6,5)$ , and the Gb green pixels are read out and averaged (1007) according to  $Gb(4,4) + Gb(4,6) + Gb(6,4) + Gb(6,6)$ .

[0053] The pixels that were binned (i.e., read out and averaged) according to FIGs. 8-10 above, are illustrated in FIG. 11 as shaded pixels. As can be seen, 2/3 of the resolution (4x4 matrix from a 6x6 matrix) of the Bayer pattern is realized. To preserve the "Bayer-like" pattern shown in FIG. 11, column 5 should be read before column 4, and row 5 should be read before row 4.

[0054] Under a VGA Bayer mode, each 6x6 pixel square should output two green pixels, one red, and one blue pixel. An exemplary scheme that realizes a VGA Bayer pattern is illustrated in FIG. 12, where pixels are averaged from three rows and three columns. Using any of the circuitry discussed above in connection with FIGs. 3-7, pixels to be averaged are designated as a first green (Gr), red (R),

second green (Gb) and blue (B). First, rows 1, 3 and 5 are enabled, and columns 1, 3, 5 and 2, 4, 6 are averaged. Next, rows 2, 4 and 6 are enabled, averaged and read out in a similar way. Under this binning scheme, no pixel data is skipped.

[0055] Another binning scheme is illustrated in FIG. 13, which averages two rows (e.g., rows 2 and 5) over three columns, thus obtaining 2/3 of the pixel data (1/3 of the pixels are skipped). Alternately, FIG. 14 illustrates a similar binning scheme where every third column is skipped in order to average out two columns and two rows, thus preserving 4/9 of the pixel data (5/9 of the pixels are skipped). It should be apparent to those skilled in the art that similar binning and averaging schemes may be made for other pixels (1.3 Meg, 4 Meg, 5 Meg, etc.) under a variety of resolutions, such as 2048x1536, 1600x1200, 1280x1024, 1024x768, etc.

[0056] FIGs. 15A-C illustrate various horizontal binning schemes that also may be used in accordance with the present invention, particularly with the FIG. 5 embodiment. Specifically, FIGs. 15A-C each disclose the first eight column storage circuits 1500 from a column storage system. The column storage circuits are substantially similar to the storage circuits 500, 501 shown in FIG. 5. Each of the eight column storage circuits 1500 have interconnecting column switches 1501-1507 that activate a binning operation between columns as discussed above in connection with FIG. 5.

[0057] To illustrate a binning operation between the eight column circuits, it is assumed that a full resolution for the eight columns is 2048x1536. In FIG. 15A, a 1/2 resolution embodiment is shown (1024x768 RGB), where the switches 1501-1504 are activated to provide binning between columns 1 and 3, 2 and 4, 5 and 7, and 6 and 8. In FIG. 15B, a 1280x1024 RGB (or alternately VGA true color, or VGA Bayer 5/9 skip) resolution is illustrated, where switches 1501, 1505 and 1506 are activated to provide binning between columns 1 and 3, 4 and 6, and 7 and 9 (not shown). Finally, FIG. 15C illustrates a VGA Bayer-type response, using a "1/3 skip" scheme, where switches 1501 and 1507, 1502 and 1505 etc., are activated so that columns 1, 3 and 5 are binned then columns 2, 4 and 6, and so on.

[0058] Referring now to FIG. 16, a subtraction of column/row pixel values is depicted in connection with an Mg-Cy-Ye-G filter array 1600. The color separation values can be calculated as  $C2-C1=(Ye+Mg)-(Cy-G)$  or  $C3-C4=(Cy+Mg)-(Ye-G)$ . In order to achieve this, the pixel reset signal is stored in the capacitor ordinarily used to store pixel signals and the pixel signal is stored on the capacitor ordinarily used to store reset signals.

[0059] For example, with reference to FIG. 6, in order to calculate color separation values, pixel signals are stored on capacitors 606, 607 and reset signals are stored on capacitors 604, 605. As a result, the values are subtracted.

[0060] It should be noted that the binning circuits and related methods described above also provide improved signal-to-noise ratio (SNR) characteristics in readout circuits, since several storage capacitors keep copies of the same signal as one signal is being read out. Consequently, the dithering that results from reading out all the copies improves SNR characteristics and color spatial noise.

[0061] An example of an imaging apparatus 2000 incorporating any of the binning circuits and related methods described above is shown in FIG. 17, and includes a lens system 2001 for directing light from an object to be imaged to the image sensing unit 2002 including an image sensor; an analog-to-digital converter 2003 for converting the image signals received at the image sensing unit 2002 into digital signals; the image/color processing unit 2005 for performing image correction processes such as color interpolation, sharpness filtering, white balancing, etc.; an output format conversion/compression unit 2007 for converting the image data into an appropriate file format for being outputted or displayed to the user; and a controller 2004 for controlling the operations of the entire imaging apparatus 2000.

[0062] The image sensor in the image sensing unit 2002 is preferably constructed as an integrated circuit which includes pixels made of a photosensitive material such as silicon. The image sensor may be formed as a

CMOS sensor and combined with a processor, such as a CPU, digital signal processor or microprocessor, in a single integrated circuit. Alternatively, the image sensor in the image sensing unit 204 may be constructed as a charge coupled device (CCD).

[0063] Without being limiting, such an imaging apparatus 2000 could be part of a computer system, camera system, scanner, machine vision system, vehicle navigation system, video telephone, surveillance system, auto focus system, star tracker system, motion detection system, image stabilization system and data compression system for high-definition television, all of which can utilize the present invention.

[0064] An exemplary processor system 4000 to which the imaging apparatus 2000 may be connected is shown in FIG. 18. The processing system 4000, such as a computer system, for example, generally comprises a central processing unit (CPU) 4001 that communicates with an input/output (I/O) device 4004 over a bus 4006. The imaging apparatus 2000 communicates with the system over bus 4006 or a ported connection. The processor system 4000 also includes random access memory (RAM) 4005, and, in the case of a computer system, may include peripheral devices such as a floppy disk drive 4002 and a compact disk (CD) ROM drive 4003 which also communicate with CPU 4001 over the bus 4006.

[0065] While the invention has been described in detail in connection with preferred embodiments known at the time, it should be readily understood that the invention is not limited to the disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Accordingly, the invention is not limited by the foregoing description or drawings, but is only limited by the scope of the appended claims